Leveraging Human Pattern-Recognition Abilities with Machine Learning to Save Lives

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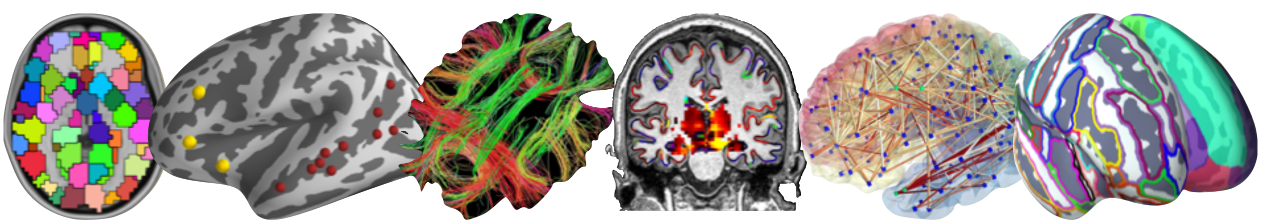
In spite of tremendous advances in computing, humans are still better than machines at finding patterns in visual data. We seek to leverage human pattern-recognition abilities with cutting-edge visualization, statistical and interaction techniques in order to save lives. Our groups' ongoing NASA- and NIH-funded research on data visualization and brain imaging will be combined with new work to create a system that will allow researchers and clinicians to better understand high-dimensional images. Specifically, we will develop an unprecedented method for "smart selection" of features in volumetric data, using new human-computer interaction devices developed in the gaming industry to train and adjust machine-learning algorithms.

BACKGROUND Identifying and quantitatively describing "regions of interest" (ROIs) in medical images is critical in both research and clinical work. This process, called "segmentation," is essential in assessing tumor stage and in planning radiation therapy and robotic surgery. At present, 3D ROIs are manually defined by technicians tracing out cross-sections of 3D image cubes on 2D "slice" images, a laborious and slow process fraught with inaccuracy. The new segmentation approach proposed will improve efficiency and reduce variability, saving lives.

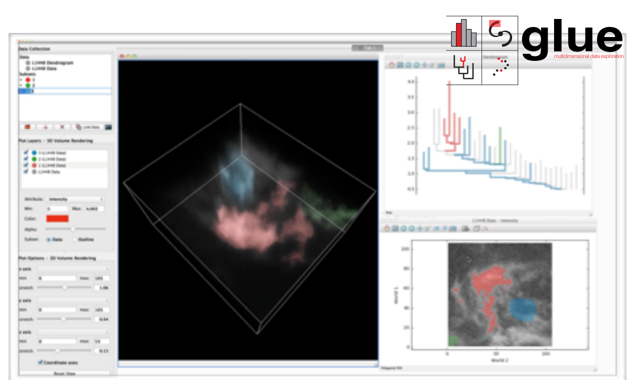
Three recent developments make the proposed research feasible now.

1. **Advances in Brain Imaging and Associated Software.** The capabilities of software packages[1] for analyzing an ever-widening variety of neuroimaging modalities have grown tremendously over the past decade. The sample brain images below all use colored highlighting to indicate salient "features." These features can be defined



algorithmically or manually, by computationally analyzing properties of the data themselves and/or by experts who markup and annotate the data. The software packages used to create these images typically suffer from two key limitations. First, they do not allow **multiple data sets** from diverse sources to be **analyzed in concert** (see #2). And, second, there is no way to draw **arbitrary surfaces** needed to make a "**selection**" in a 3D volumetric view. A standard computer mouse can be used trace out a region of interest on a 2D image, but at present there is no analogous device to draw a surface to trace out a volume of interest in 3D (see #3).

2. **Linked-view Visualization and the Advent of "Glue."** The human visual perceptual system is especially good at detecting change. So data visualization systems offering so-called "linked views," where one on-screen map, chart or graph data set updates *live* to reflect selections made in another serve as insight engines. Linked-views of tabular and mapping data have become popular recently, especially in business analytics, as data sets grow in size and diversity. We have recently developed the world's first visualization system that allows linking of data sets and displays for



[1]See nitrc.org for a comprehensive searchable listing of neuroimaging projects and software.

images and three-dimensional data formats. This system, called "Glue," is supported by NASA because it offers astronomers a way to analyze and make the best use of the three-dimensional data that comes from so-called spectroscopic data cubes. As in our earlier collaborative work on Astronomical Medicine, Glue is just as useful for analyzing three-dimensional medical image cubes, such as MRI and CT scans, as it is for astronomy. As illustrated in screenshot above, Glue propagates selections made in one data view, live, across all views, leveraging the human ability to see change, revealing hidden meaning in data. (Short demo videos: 2D , 3D)

3. **Advances in Computer Gaming and Interaction Devices** Computer animation and interaction techniques today are propelled forward fastest by the tremendous profitability of games. Innovative new devices allow humans to interact with virtual environments in more and more immersive ways as computers get more powerful and as profits grow. The most exciting opportunity on the horizon is the potential of devices like Microsoft's new HoloLens to blend the real world, such as a person's real hand, with holographic projections, like the image of a human heart shown in the image at right.

PROBLEM TO BE SOLVED Glue allows salient regions to be outlined and selected in its 2D views (e.g. within images or graphs), but selection in 3D views is onerous and limited. 3D selection in Glue presently uses combinations of simple shapes (e.g. spheres, prisms). But, brain structures and tumors do not have such simple shapes. To understand the tremendous wealth of 3D data available to researchers, **we need to develop "smart selection" in 3D.** Smart selection applied to the 2D eye at right lets you click and drag roughly around the iris' edge, and then, when you release the mouse button, your inexact tracing magically morphs into an excellent outline (red dashed line) of the iris. This 2D process involves both "selection" (outlining the object) and "segmentation" (the decision of where to put the iris' boundary).

In both 2D and 3D, the segmentation problem is solved for relatively sharp-edged objects (like the edge of an iris) For fuzzy features, though, in both astronomical and medical data, expert researchers are still better than algorithms alone at defining boundaries of salient features.

PROPOSED SOLUTION Our recent work[2] used the output of manual segmentations of 2D multi-color images of nebulae to train a machine learning algorithm to find similar nebulae. If we extend that 2D work to 3D, we can **use experts' segmentations of brain imaging to train 3D selection tools**. An extensive catalog of such expert segmentation has already been assembled by the MGH/HMS members of our team and their colleagues (braintumorsegmentation.org). By adapting our 2D machine learning techniques to 3D, and using the expert-created segmentations as training for those algorithms, we can create a "smart" 3D selection tool. To implement that tool in Glue, we also need the equivalent of the mouse that would used in the 2D smart selection eye example, above. We believe that the **HoloLens** is likely to offer a solution. If we project brain imaging data as a hologram, using HoloLens, a researcher should be able to use their real hands to "draw" a rough selection surface (analogous to the dashed red line around the iris in the 2D image above) within the 3D holographically-projected volumetric data. The ability to make smart selections within 3D images will speed the pace of medical research, and have immediate clinical applications. We love the idea that software and techniques originally developed to study arcane questions about our Universe could ultimately save lives, and would like to try it.

STAFFING, BUDGET, SUCCESS **Goodman** leads the Seamless Astronomy group at FAS, which develops Glue. She and Borkin founded the *Astronomical Medicine* project, of which this work is an outgrowth. **Borkin** is an expert on human-computer interaction. **Rosen**, trained as an MD-PhD physicist, leads the Martinos Center, and is expert in neuroimaging. **Kalpathy-Cramer** is an expert on quantitative image analysis, and is a leader in the *The Multimodal Brain Tumor Image Segmentation Benchmark (BRATS)* project that will provide training data for this project. **Goodman** and **Rosen** both have extensive leadership experience, and the requested $200K will be used for one of their labs to host a part-time postdoctoral fellow and/or graduate student who will carry out this project, and to purchase a HoloLens. Our **goal** is a working smart 3D selection system implemented in Glue. Given the unprecedented nature of what we propose, a smart 3D selection without HoloLens, or a manual HoloLens-based 3D selection tool, would be successes on their own, with immediate applicability in clinical and research settings.

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[2]Beaumont, Goodman, et al. *Brut: Automatic bubble classifier,* http://adsabs.harvard.edu/abs/2014ascl.soft07016B